4.3.7 Geological Hazards

The following section provides the hazard profile (hazard description, location, extent, previous occurrences and losses, probability of future occurrences, and impact of climate change) and vulnerability assessment for the geological hazards in Morris County.

2020 HMP Changes

- All subsections have been updated using best available data.
- Previous occurrences were updated with events that occurred between 2014 and 2019.
- Updated New Jersey Geological Survey and Water landslide susceptibility data (2016) was utilized for the risk assessment.

4.3.7.1 Profile

Hazard Description

Landslides

According to the U.S. Geological Survey (USGS), the term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Although gravity acting on an over steepened slope is the primary reason for a landslide, there are other contributing factors (USGS 2013). Among the contributing factors are: (1) erosion by rivers, glaciers, or ocean waves which create over-steepened slopes; (2) rock and soil slopes weakened through saturation by snowmelt or heavy rains; (3) earthquakes which create stresses making weak slopes fail; and (4) excess weight from rain/snow accumulation, rock/ore stockpiling, waste piles, or man-made structures. Scientists from the USGS also monitor stream flow, noting changes in sediment load in rivers and streams that may result from landslides. All of these types of landslides are considered aggregately in USGS landslide mapping.

In New Jersey, there are four main types of landslides: slumps, debris flows, rockfalls, and rockslides. Slumps are coherent masses that move downslope by rotational slip on surfaces that underlie and penetrate the landslide deposit (Briggs et al 1975). A debris flow, also known as a mudslide, is a form of rapid mass movement in which loose soil, rock, organic matter, air, and water mobilize as slurry that flows downslope. Debris flows are often caused by intense surface water from heavy precipitation or rapid snow melt. This precipitation loosens surface matter, thus triggering the slide. Rockfalls are common on roadway cuts and steep cliffs. These landslides are abrupt movements of geological material such as rocks and boulders. Rockfalls happen when these materials become detached. Rockslides are the movement of newly detached segments of bedrock sliding on bedrock, joint, or fault surfaces (Delano and Wilshusen 2001).

Although gravity acting on an over-steepened slope is the primary reason for a landslide, there are other contributing factors that include:

- Erosion by rivers, glaciers, or ocean waves create over-steepened slopes
- Rock and soil slopes are weakened through saturation by snowmelt or heavy rains
- Earthquakes create stresses that make weak slopes fail
- Earthquakes of magnitude 4.0 and greater have been known to trigger landslides
- Volcanic eruptions produce loose ash deposits, heavy rain, and debris flows
- Excess weight from accumulation of rain or snow or stockpiling of rock or ore, from waste piles or man-made structures may stress weak slopes to failure (USGS 2013).

Landslides may be triggered by both natural and human-caused changes in the environment. Warning signs for landslide activity include:

- Springs, seeps, or saturated ground in areas that have not typically been wet before
- New cracks or unusual bulges in the ground, street pavement, or sidewalk
- Soil moving away from foundations
- Ancillary structures, such as decks and patios, tilting and moving relative to the main house
- Tilting or cracking of concrete floors and foundations
- Broken water lines and other underground utilities
- Leaning telephone poles, trees, retaining walls, or fences
- Offset fence lines
- Sunken or down-dropped road beds
- Rapid increase in creek water levels, possibly accompanied by increased turbidity
- Sudden increase in creek water levels while rain is still falling or just recently ended
- Sticking doors and windows, and visible open spaces indicating jambs and frames out of plumb
- A faint rumbling sound that increases in volume as the landslide nears
- Unusual sounds, such as trees cracking or boulders knocking together (USGS 2013).

Subsidence/Sinkholes

Land subsidence can be defined as the sudden sinking or gradual downward settling of the earth's surface with little or no horizontal motion, owing to the subsurface movement of earth materials (USGS 2000). Subsidence often occurs through the loss of subsurface support in karst terrain, which may result from a number of natural- and human-caused occurrences. Karst describes a distinctive topography that indicates dissolution of underlying carbonate rocks (limestone and dolomite) by surface water or groundwater over time. The dissolution process causes surface depressions and the development of sinkholes, sinking stream, enlarged bedrock fractures, caves, and underground streams (NJOEM 2019).

Sinkholes, the type of subsidence most frequently seen in the New Jersey, are a natural and common geologic feature in areas with underlying limestone, carbonate rock, salt beds, or other rocks that are soluble in water. Over periods of time, measured in thousands of years, the carbonate bedrock can be dissolved through acidic rain water moving in fractures or cracks in the bedrock. This creates larger openings in the rock through which water and overlying soil materials will travel. Over time the voids will enlarge until the roof over the void is unable to support the land above will collapse forming a sinkhole. In this example the sinkhole occurs naturally, but in other cases the root causes of a sinkhole are anthropogenic. These anthropogenic causes can include those that involve changes to the water balance of an area such as: over-withdrawal of groundwater; diverting surface water from a large area and concentrating it in a single point; artificially creating ponds of surface water; and drilling new water wells. These actions can serve to accelerate the natural processes of creation of soil voids, which can have a direct impact on sinkhole creation (NJOEM 2019).

Both natural and man-made sinkholes can occur without warning. Slumping or falling fence posts, trees, or foundations, sudden formation of small ponds, wilting vegetation, discolored well water, and/or structural cracks in walls and floors, are all specific signs that a sinkhole is forming. Sinkholes can range in form from steep-walled holes, to bowl, or cone-shaped depressions. When sinkholes occur in developed areas they can cause severe property damage, disruption of utilities, damage to roadways, injury, and loss of life (NJOEM 2019).

Location

Landslides

Landslides are common in New Jersey, primarily in the northern region of the State. The New Jersey Geologic Survey (currently known as the New Jersey Geological and Water Survey) determined landslide susceptibility for nine counties in New Jersey (Bergen, Essex, Hudson, Middlesex, Monmouth, Morris, Passaic, Somerset, and Union). Areas within these counties are classified into Class A, B, and C landslide susceptible classes, and several subclasses within the main classifications. These classes are consistent with HAZUS User Manual Table 9.2. Class A areas in New Jersey include classes AII, AIV, AVI which is strongly cemented rock at varying slope angles; Class B includes classes BIII, BIV, BV, and BVI which includes weakly cemented rock and soil at varying slope angles; and Class C includes classes CV, CVI, CVII, CIX, and CX which includes shale and clayey soil at varying slope angles.

Figure 4.3.7-1 shows landslide susceptibility in Morris County. A majority of the County is not susceptible to landslides, however there are small areas throughout the County that are susceptible (Class AI, AII, AIV, AVI, BIII, BIV, and BV). An exposure analysis found that 11.6 square miles of Morris County is susceptible to landslides. There are just under 5 square miles located in the Class A landslide susceptible area and 6.9 square miles in the Class B landslide susceptible area. Refer to the Vulnerability Assessment later in this section which identifies the assets located in the landslide susceptibility area by municipality.

Subsidence/Sinkholes

New Jersey is susceptible to the effects of subsidence and sinkholes, primarily in the northern region of the State. The State's susceptibility to subsidence is due in part to the number of abandoned mines throughout New Jersey. The State historically was an iron-producing state and the first mines in New Jersey were drilled in the early 1700s, with operations continuing until 1986 when the last active mine was closed. Although mines have closed in New Jersey, continued development in the northern part of the State has been problematic because of the extensive mining that occurred there, which has caused widespread subsidence. One problem is that the mapped locations of some of the abandoned mines are not accurate. Another issue is that many of the surface openings were improperly filled in, and roads and structures have been built adjacent to or on top of these former mine sites.

Figure 4.3.7-2 shows the location of the mapped abandoned mines in New Jersey. The data from NJGWS and the figure indicate that Morris County has more than 100 abandoned mines. The majority of the mines in Morris County were magnetite mines with several mica and graphite mines. Abandoned mines are largely located in the northwestern half of the County (NJGWS 2006).

Figure 4.3.7-1. Landslide Susceptibility in Morris County

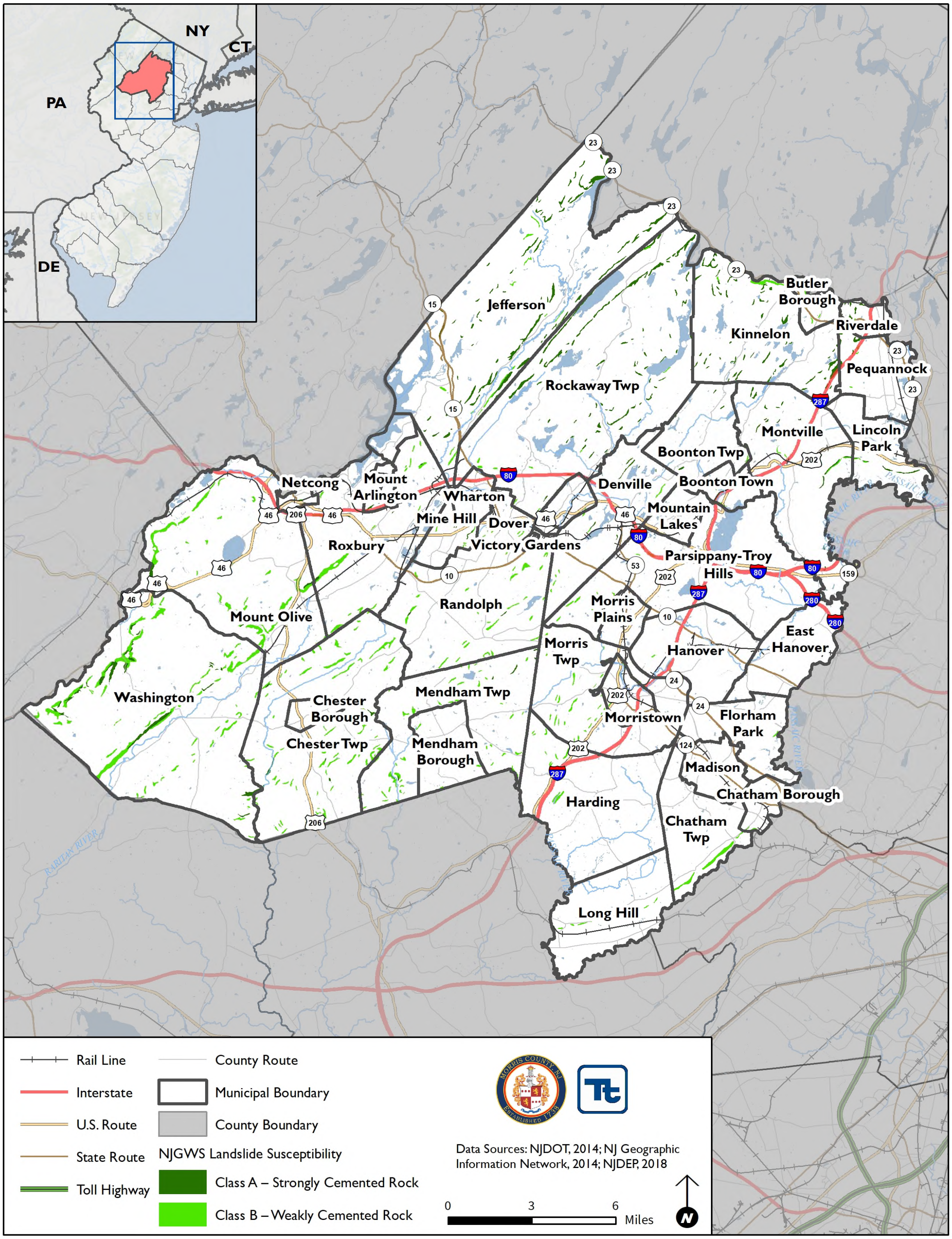
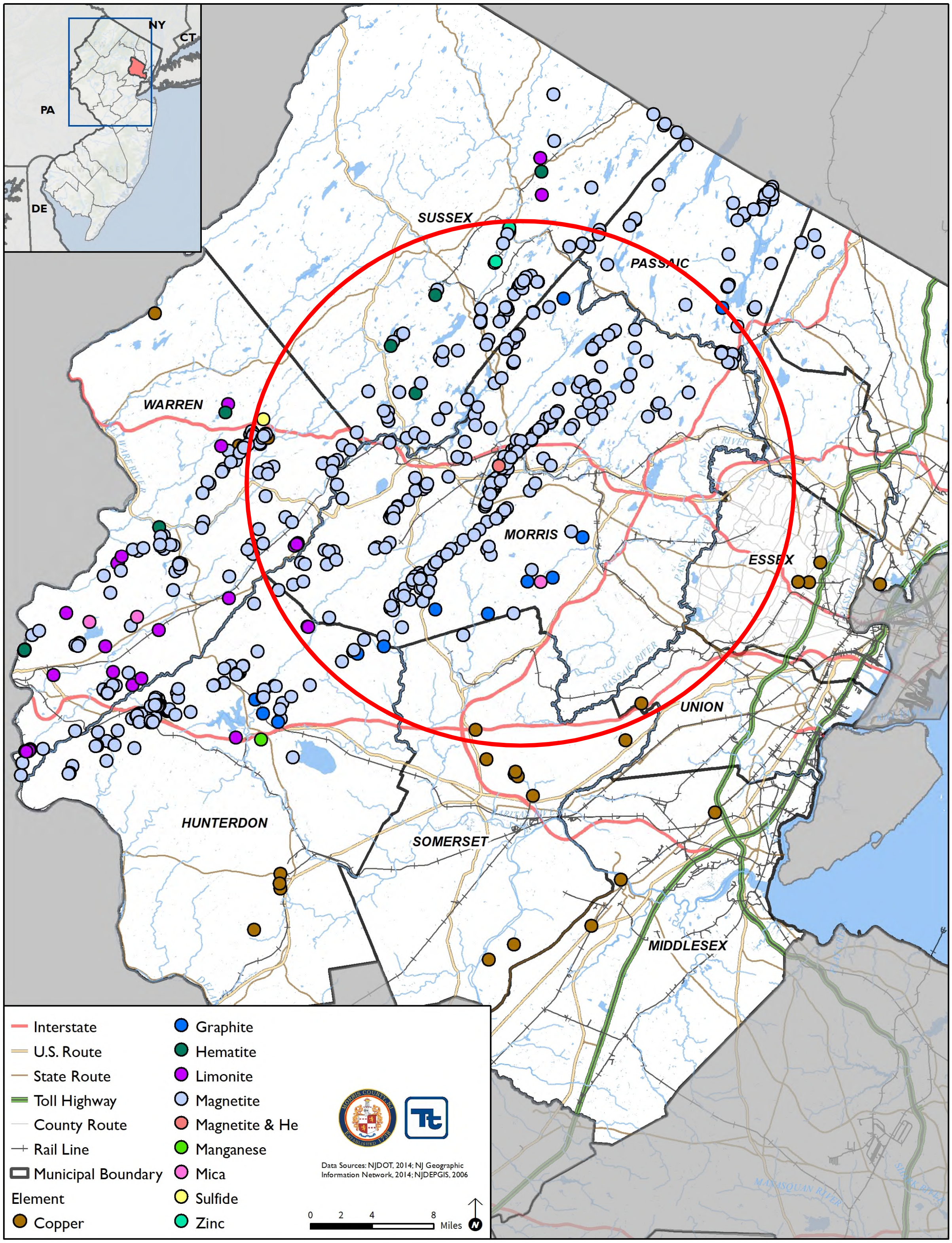


Figure 4.3.7-2. Abandoned Mines in New Jersey



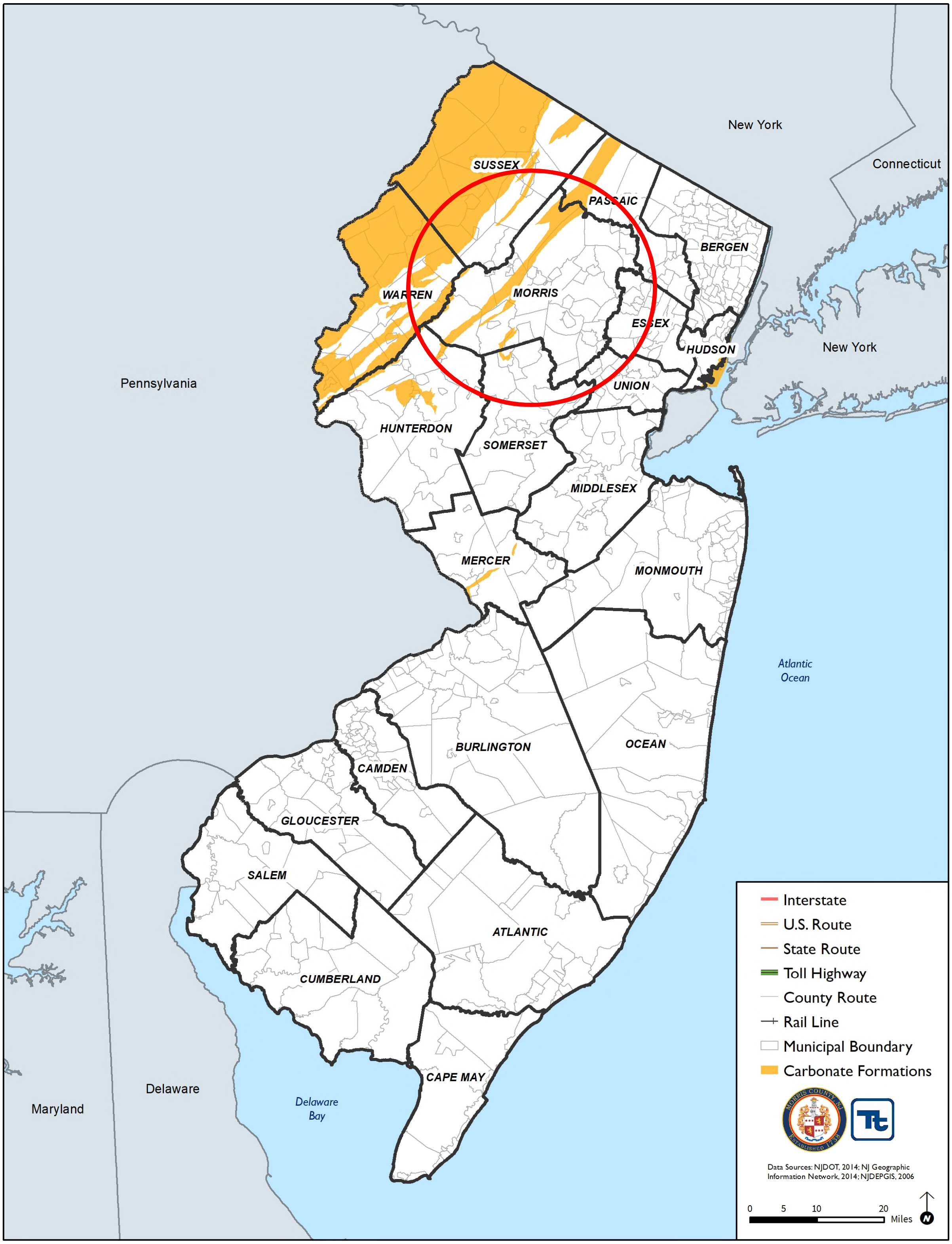
Note: The red circle indicates the location of Morris County.

Naturally occurring subsidence and sinkholes in New Jersey occur within bands of carbonate bedrock. In northern New Jersey, there are more than 225 square miles that are underlain by limestone, dolomite, and marble. In some areas, no sinkholes have appeared, while in others, sinkholes are common. No collapsed sinkholes have been identified; however, there are some features which could be either very shallow solution depressions or wind blowout features. Sinkholes in New Jersey are generally concentrated in the northwestern part of the State.

Areas underlain by carbonate rock may contain surface depressions and open drainage passages making such areas unstable and susceptible to subsidence and surface collapse. As a result, the alteration of drainage patterns, placement of impervious coverage, grade changes or increased loads can result in land subsidence and sinkhole formation (Piefer 2006).

Figure 4.3.7-3 illustrates the locations of carbonate-bearing geologic formations of New Jersey. These formations are areas of potential natural subsidence. These geologic units contain a high enough percentage of carbonate minerals such as calcite and/or dolomite for karst features such as sinkholes to form. Some of these units are more prone to sinkhole development than others due to a greater carbonate content in the rock. Although not every unit listed has documented sinkholes, all are susceptible to dissolution by groundwater so various karst features, including sinkholes, may be found on any of these units. According to this figure, Morris County contains carbonate rock formations in a narrow area running from the southwest to the northeast in the western portion of the County. The municipalities containing carbonate rock formations are Township of Jefferson, Rockaway Township, Township of Roxbury, Township of Mount Olive, Township of Washington, and Chester Township.

Figure 4.3.7-3. Carbonate Rock Regions of New Jersey



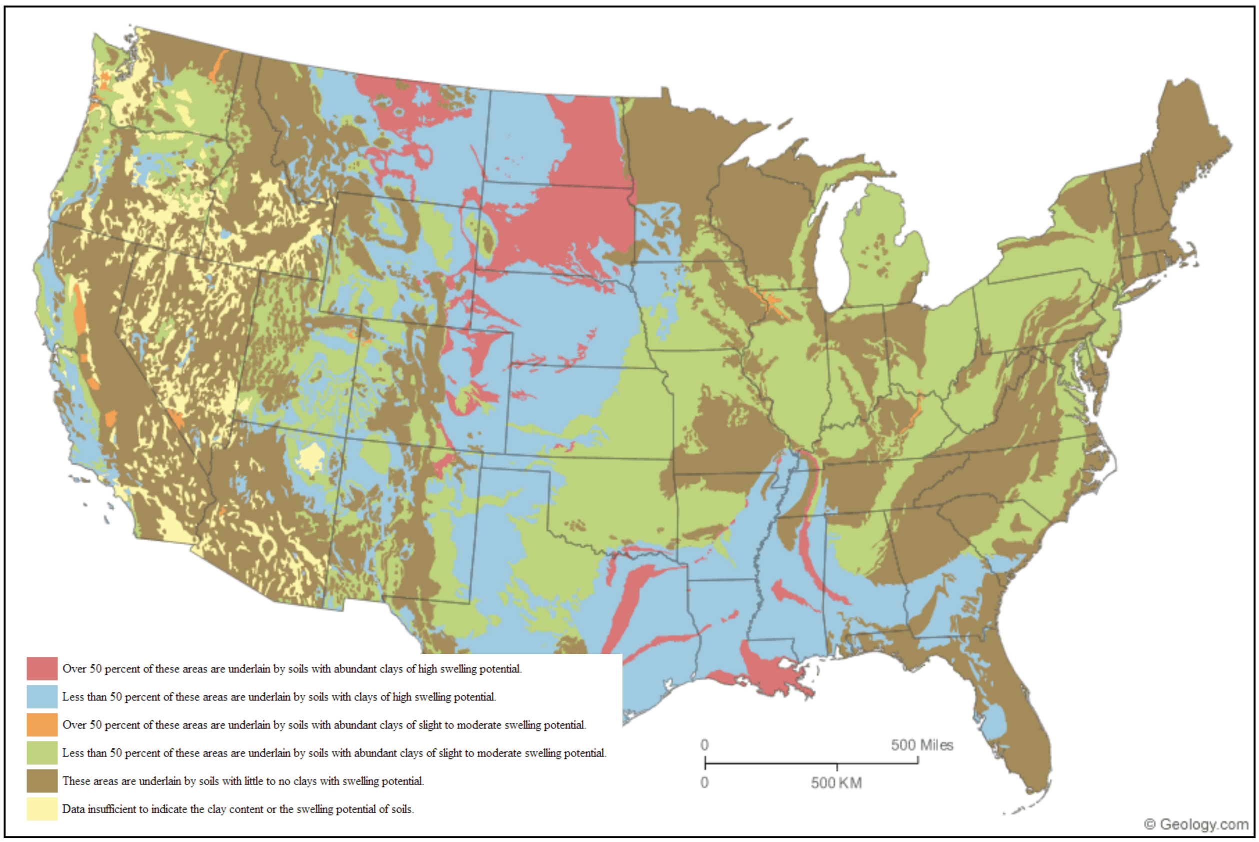
Note: *The red circle indicates the location of Morris County.*

While fewer karst features have been mapped in existing urban areas, human activity can often be the cause of a subsidence or sinkhole event. Furthermore, the lack of karst features exhibited in maps of urban areas is likely a result of development activities that disguise, cover, or fill existing features rather than an absence of the features themselves. Leaking water pipes or structures that convey stormwater runoff may also result in areas of subsidence as the water dissolves substantial amounts of rock over time. In some cases, construction, land grading, or earthmoving activities that cause changes in stormwater flow can trigger sinkhole events. Subsidence or sinkhole events may occur in the presence of mining activity, especially in areas where the cover of a mine is thin, even in areas where bedrock is not necessarily conducive to their formation. Piggott and Eynon (1978) indicated that sinkhole development normally occurs where the interval to the ground surface is less than three to five times the thickness of the extracted seam, and the maximum interval is up to ten times the thickness of the extracted seam. Sub-surface (i.e. underground) extraction of materials such as oil, gas, coal, metal ores (copper, iron, and zinc), clay, shale, limestone, or water may result in slow-moving or abrupt shifts in the ground surface.

Expansive Soils

Portions of New Jersey are underlain by soils with little to no clays with swelling potential. Morris County is mainly underlain by areas with little to no clays with swelling potential with some areas of less than 50 percent of the area underlain by soils with abundant clays of slight to moderate swelling potential located in the eastern portions of the County (Figure 4.3.7-4).

Figure 4.3.7-4. Expansive Soils of the United States



Source: Geology.com 2014

Extent

Landslide

To determine the extent of a landslide hazard, the affected areas need to be identified and the probability of the landslide occurring within some time period needs to be assessed. Natural variables that contribute to the overall extent of potential landslide activity in any particular area include soil properties, topographic position and slope, and historical incidence. Predicting a landslide is difficult, even under ideal conditions and with reliable information. As a result, the landslide hazard is often represented by landslide incidence and/or susceptibility, as defined below:

- Landslide incidence is the number of landslides that have occurred in a given geographic area. High incidence means greater than 15% of a given area has been involved in landsliding; medium incidence means that 1.5 to 15% of an area has been involved; and low incidence means that less than 1.5% of an area has been involved (Geological Hazards Program Date Unknown).
- Landslide susceptibility is defined as the probable degree of response of geologic formations to natural or artificial cutting, to loading of slopes, or to unusually high precipitation. It can be assumed that unusually high precipitation or changes in existing conditions can initiate landslide movement in areas where rocks and soils have experienced numerous landslides in the past. Landslide susceptibility depends on slope angle and the geologic material underlying the slope. Landslide susceptibility only identifies areas potentially affected and does not imply a time frame when a landslide might occur. High, medium, and low susceptibility are delimited by the same percentages used for classifying the incidence of landsliding (Geological Hazards Program Date Unknown).

Subsidence/Sinkhole

Subsidence and sinkholes occur slowly and continuously over time or abruptly for various reasons. Subsidence and sinkholes can occur due to either natural processes (karst sinkholes in areas underlain by soluble bedrock) or as a result of human activities. Subsidence in the U.S. has directly affected more than 17,000 square miles in 45 states, and associated annual costs are estimated to be approximately $125 million. The principal causes of subsidence are aquifer-system compaction, drainage of organic soils, underground mining, hydrocompaction, natural compaction, sinkholes, and thawing permafrost (Galloway 2000). There are several methods used to measure land subsidence. Global Positioning System (GPS) is a method used to monitor subsidence on a regional scale. Benchmarks (geodetic stations) are commonly space around four miles apart (State of California 2014).

Another method which is becoming increasingly popular is Interferometric Synthetic Aperture Radar (InSAR). InSAR is a remote sensing technique that uses radar signals to interpolate land surface elevation changes. It is a cost-effective solution for measuring land surface deformation for a region while offering a high degree of spatial detail and resolution (State of California 2014).

Expansive Soils

The plasticity index (PI) is expressed as the numerical difference between the plastic limit (the percent moisture content at which clay passes from the solid to the plastic state) and the liquid limit (the percent moisture content at which clay passes from the plastic to liquid state). The PI bears a direct relation to the amount and type of clay minerals present and to the orientation and size of clay particles. Other factors remain constant, the PI increases with amount of clay minerals, decreases with degree of parallel orientation of the clay minerals, and decreases with clay particle size (FEMA 1996).

The PI is generally a good indicator of swelling potential. Scientists have found the PI to be one of the most useful indicators of swelling potential. Expansive soils can be recognized either by visual inspection in the field or by conducting laboratory analyses (FEMA 1996).

Previous Occurrences and Losses

Between 1954 and 2019, FEMA issued a disaster (DR) or emergency (EM) declaration for the State of New Jersey for one geological hazard-related event, classified as a mudslide. Morris County was included in this declaration. DR-1337 was declared for severe storms, flooding, and mudslides which took place from August 12-21, 2000 (FEMA 2019).

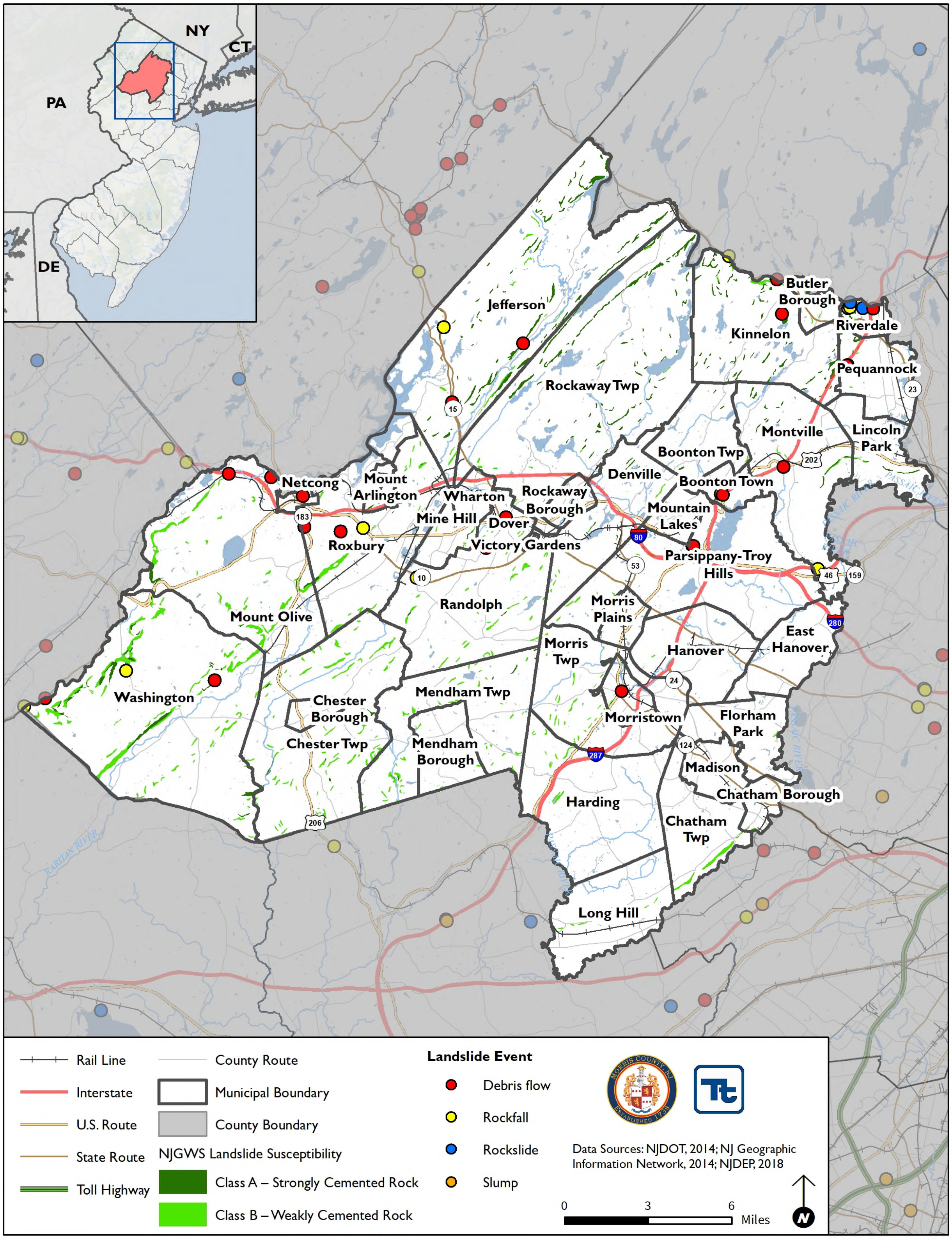
Figure 4.3.7-5 illustrates historic events landslide events in Morris County. This dataset is dated from 1782 to 2018 and does not reflect more recent events. According to the NJ State HMP and other databases researched, there are no recent geological hazard events that have impacted Morris County (2014 and 2019). Smaller scale geologic events may not be documented in databases available for this HMP update.

Probability of Future Occurrences

Based upon risk factors for and past occurrences, it is likely that geological hazards will occur in Morris County in the future. It is estimated that Morris County will continue to experience direct and indirect impacts of geological hazards and its impacts on occasion, with the secondary effects causing potential disruption or damage to communities (i.e., roads, infrastructure, buildings).

In Section 4.4, the identified hazards of concern for Morris County were ranked. The probability of occurrence, or likelihood of the event, is one parameter used for hazard rankings. Based on historical records and input from the Planning Committee, the probability of occurrence for geological hazards in the County is considered 'occasional'.

Figure 4.3.7-5. Landslide Susceptibility Areas and Historic Landslide Events



Climate Change Impacts

Future climate change may impact storm patterns, increasing the probability of more frequent, intense storms with varying duration. Increase in global temperature could affect the snowpack and its ability to hold and store water. Warming temperatures also could increase the occurrence and duration of droughts, which could increase the probability of wildfire, reducing the vegetation that helps to support steep slopes. All of these factors could increase the probability for landslide occurrences.

Landslides

Both northern and southern New Jersey have become wetter over the past century. Northern New Jersey's 1971-2000 precipitation average was over five inches (12%) greater than the average from 1895-1970 (Office of New Jersey State Climatologist). Annual precipitation in New Jersey has been 8-percent above average during the last 10 years; and has experienced an upward trend of 4.1 inches in precipitation in 100-years (NJDEP 2019).

Climate change may impact storm patterns, increasing the probability of more frequent, intense storms with varying duration. Increase in global temperature could affect the snowpack and its ability to hold and store water. Warming temperatures also could increase the occurrence and duration of droughts, which would increase the probability of wildfire, reducing the vegetation that helps to support steep slopes. All of these factors may increase the probability for landslide occurrences.

Subsidence/Sinkholes

Similar to landslides, climate change will affect subsidence and sinkholes in New Jersey. As discussed, one of the triggers for subsidence and sinkholes is an abundance of moisture which has the potential to permeate the bedrock causing an event. Climatologists expect an increase in annual precipitation amounts. This increase will coincide with an increased risk in subsidence and sinkholes in vulnerable areas.

Expansive Soils

As the climate changes and temperatures increase, soils have the potential to dry out, resulting in expansive soils shrinking and failing. This could lead to a big problem in residential areas where buildings have shallow foundations; the soils will be unable to support the weights of a building. When expansive soils get dry, they begin to repel moisture instead of soaking it up. The water is more likely to run off, creating flash floods. It takes a slow and steady rain, over an extended period of time, to restore expansive clay soils (Gehr 2014).

4.3.7.2 Vulnerability Assessment

To understand risk, a community must evaluate what assets are exposed and/or vulnerable to the identified hazard. For Morris County, the NJGWS landslide susceptibility area and carbonate rock datasets was used to evaluate exposure to this hazard. The following text summarizes the potential impact of geological hazards on the County. Refer to Section 4.2 (Methodology and Tools) for additional details on the methodology used to assess geological hazard risk.

Impact on Life, Health and Safety

Generally, a landslide or subsidence event would be an isolated incidence and impact the populations within the immediate area of the incident. Specifically, the population located downslope of the landslide hazard areas are particularly vulnerable to this hazard. In addition to causing damages to residential buildings and displacing residents, landslides and subsidence events can block off or damage major roadways and inhibit travel for emergency responders or populations trying to evacuate the area.

Table 4.3.7-1 summarizes the population located in Class A, Class B landslide susceptible areas, and carbonate rock susceptible to natural subsidence/sinkholes. The Town of Morristown has the greatest number of persons living in the landslide susceptible Class A area (50 people which is less than 1% of the Town's total population). The Township of Washington has the greatest number of persons living in the landslide susceptible Class B area (262 people or 1.4% of the Township's total population), and the Township of Roxbury has the great number of persons residing in structures built on carbonate rock (7,328 people or 31.2-percent of the Township's total population).

Table 4.3.7-1. Estimated Population Located in the Geologic Hazard Areas

Municipality	American Community Survey (2013-2017) Population	Class A Landslide Suscept-ibility Area	Percent (%) Total	Class B Landslide Suscept-ibility Area	Percent (%) Total	Carbonate Rock	Percent (%) of Total
Town of Boonton	8,390	0	0.0%	44	0.5%	0	0.0%
Township of Boonton	4,353	0	0.0%	36	0.8%	0	0.0%
Borough of Butler	7,780	0	0.0%	6	0.1%	0	0.0%
Chatham Borough	9,003	0	0.0%	32	0.4%	0	0.0%
Chatham Township	10,507	0	0.0%	240	2.3%	0	0.0%
Chester Borough	1,540	0	0.0%	0	0.0%	0	0.0%
Chester Township	7,931	3	0.0%	65	0.8%	538	6.8%
Denville Township	16,822	18	0.1%	65	0.4%	0	0.0%
Town of Dover	18,307	0	0.0%	62	0.3%	0	0.0%
Township of East Hanover	11,241	0	0.0%	0	0.0%	0	0.0%
Borough of Florham Park	11,792	0	0.0%	68	0.6%	0	0.0%
Township of Hanover	14,436	0	0.0%	0	0.0%	0	0.0%
Township of Harding	3,887	0	0.0%	95	2.4%	0	0.0%
Township of Jefferson	21,440	26	0.1%	35	0.2%	1,013	4.7%

Municipality	American Community Survey (2013-2017) Population	Class A Landslide Suscept-ibility Area	Percent (%) Total	Class B Landslide Suscept-ibility Area	Percent (%) Total	Carbonate Rock	Percent (%) of Total
Borough of Kinnelon	10,242	63	0.6%	3	0.0%	0	0.0%
Borough of Lincoln Park	10,464	101	1.0%	0	0.0%	0	0.0%
Township of Long Hill	8,763	0	0.0%	154	1.8%	0	0.0%
Borough of Madison	16,080	0	0.0%	0	0.0%	0	0.0%
Borough of Mendham	4,992	0	0.0%	14	0.3%	3	0.1%
Township of Mendham	5,877	13	0.2%	80	1.4%	311	5.3%
Township of Mine Hill	3,609	0	0.0%	0	0.0%	545	15.1%
Township of Montville	21,739	68	0.3%	13	0.1%	0	0.0%
Township of Morris	22,498	0	0.0%	94	0.4%	0	0.0%
Borough of Morris Plains	5,605	0	0.0%	0	0.0%	0	0.0%
Town of Morristown	18,833	150	0.8%	60	0.3%	0	0.0%
Borough of Mount Arlington	5,405	0	0.0%	0	0.0%	0	0.0%
Township of Mount Olive	29,010	0	0.0%	212	0.7%	6,446	22.2%
Borough of Mountain Lakes	4,309	0	0.0%	0	0.0%	0	0.0%
Netcong Borough	3,245	0	0.0%	0	0.0%	0	0.0%
Township of Parsippany-Troy Hills	53,444	0	0.0%	39	0.1%	0	0.0%
Township of Pequannock	15,499	0	0.0%	20	0.1%	0	0.0%
Township of Randolph	25,918	3	0.0%	178	0.7%	325	1.3%
Borough of Riverdale	4,238	13	0.3%	0	0.0%	1,261	29.7%
Borough of Rockaway	6,473	0	0.0%	0	0.0%	0	0.0%
Township of Rockaway	24,758	13	0.1%	26	0.1%	86	0.3%
Township of Roxbury	23,458	7	0.0%	19	0.1%	7,328	31.2%
Borough of Victory Gardens	1,655	0	0.0%	0	0.0%	0	0.0%
Township of Washington	18,713	14	0.1%	262	1.4%	3,664	19.6%
Borough of Wharton	6,591	0	0.0%	0	0.0%	0	0.0%
Morris County (Total)	**498,847**	**491**	**0.1%**	**1,920**	**0.4%**	**21,519**	**4.3%**

Sources: American Community Survey 5-year Estimate, 2017; NJGWS, 2015

Note: Class A includes classes AII, AIV, AVI which is strongly cemented rock at varying slope angles. Class B includes classes BIII, BIV, BV, and BVI which includes weakly cemented rock and soil at varying slope angles.

NJGWS New Jersey Geological Water Survey

Socially vulnerable populations (e.g. the elderly and low-income populations) are particularly vulnerable to a hazard event. Within Class A areas, there are approximately 72 people over the age of 65 and 24 people below the poverty level. As for populations within Class B areas, there are approximately 283 people over the age 65 and 80 people considered low income populations.

Impact on General Building Stock

In general, the built environment located in the high landslide susceptibility area and the population, structures and infrastructure located downslope are vulnerable to this hazard. Landslides also have the potential of destabilizing the foundation of structures, which may result in monetary losses to businesses and residents. There are 189,129 buildings with a replacement cost value of $127 billion located in these landslide hazard areas countywide. The Borough of Lincoln Park has the greatest number of buildings located in Class A areas with 34 buildings (less than 1% of the Borough's total number of buildings) with an estimated replacement cost of $11.8 million, while the Township of Washington has the greatest number of buildings located in Class B areas with 110 buildings (1.4% of the Township's total) with an estimated replacement cost of $56 million. Table 4.3.7-4 summarizes the exposed building stock located in Class A and Class B landslide susceptibility areas by municipality.

Table 4.3.7-3 summarizes the building stock constructed on carbonate rock by municipality and potentially susceptible to natural subsidence/sinkholes. In total, there are 9,382 buildings are located on carbonate rock countywide. This is equal to approximately $7.8 billion of the total replacement costs for buildings in Morris County. The Township of Roxbury has the greatest number of buildings constructed on carbonate rock (39.1% of the Township's total number of buildings) with an estimated replacement cost of approximately $2.6 billion.

Table 4.3.7-2. Number of Buildings in the Class A and Class B Landslide Hazard Area by Municipality

			Class A				Class B			
Municipality	Total Number of Buildings	Total Replacement Cost Value (RCV)	Number of Buildings - Class A	% of Total	RCV - Class A	% of Total	Number of Buildings - Class B	% of Total	RCV - Class B	% of Total
Town of Boonton	3,262	$1,832,625,537	0	0.0%	$0	0.0%	16	0.5%	$6,219,298	0.3%
Township of Boonton	1,898	$1,388,780,135	0	0.0%	$0	0.0%	14	0.7%	$4,669,558	0.3%
Borough of Butler	2,701	$1,489,686,071	0	0.0%	$0	0.0%	2	0.1%	$935,998	0.1%
Chatham Borough	3,286	$1,673,960,469	0	0.0%	$0	0.0%	11	0.3%	$6,678,513	0.4%
Chatham Township	4,080	$2,300,237,613	0	0.0%	$0	0.0%	78	1.9%	$63,220,964	2.7%
Chester Borough	853	$694,668,411	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Chester Township	3,680	$2,782,631,274	1	0.0%	$853,072	0.0%	30	0.8%	$16,388,570	0.6%
Denville Township	7,198	$4,397,845,504	7	0.1%	$2,101,954	0.0%	21	0.3%	$14,975,859	0.3%
Town of Dover	4,514	$2,640,787,978	0	0.0%	$0	0.0%	14	0.3%	$5,262,947	0.2%
Township of East Hanover	4,848	$4,740,072,304	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Borough of Florham Park	3,805	$3,768,421,982	0	0.0%	$0	0.0%	17	0.4%	$14,433,510	0.4%
Township of Hanover	7,090	$5,609,469,027	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Harding	2,230	$1,808,255,972	0	0.0%	$0	0.0%	43	1.9%	$21,314,927	1.2%
Township of Jefferson	9,625	$4,421,074,958	14	0.1%	$4,334,836	0.1%	14	0.1%	$4,512,106	0.1%
Borough of Kinnelon	4,093	$2,858,766,250	27	0.7%	$20,831,575	0.7%	1	0.0%	$1,410,001	0.0%
Borough of Lincoln Park	4,166	$2,125,371,898	34	0.8%	$11,871,322	0.6%	0	0.0%	$0	0.0%
Township of Long Hill	3,643	$2,253,461,094	0	0.0%	$0	0.0%	54	1.5%	$25,652,702	1.1%
Borough of Madison	6,301	$3,066,320,935	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Borough of Mendham	2,139	$1,479,178,043	0	0.0%	$0	0.0%	5	0.2%	$5,985,022	0.4%

Municipality	Total Number of Buildings	Total Replacement Cost Value (RCV)	Class A				Class B			
			Number of Buildings - Class A	% of Total	RCV - Class A	% of Total	Number of Buildings - Class B	% of Total	RCV - Class B	% of Total
Township of Mendham	2,667	$2,099,041,883	5	0.2%	$2,050,578	0.1%	34	1.3%	$33,243,377	1.6%
Township of Mine Hill	1,590	$766,971,485	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Montville	8,179	$6,714,034,036	25	0.3%	$12,859,883	0.2%	5	0.1%	$3,434,347	0.1%
Township of Morris	9,713	$6,091,077,654	0	0.0%	$0	0.0%	36	0.4%	$26,562,465	0.4%
Borough of Morris Plains	2,378	$1,738,775,034	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Town of Morristown	4,413	$2,945,511,672	25	0.6%	$7,711,229	0.3%	14	0.3%	$22,927,023	0.8%
Borough of Mount Arlington	2,333	$1,065,424,961	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Mount Olive	9,115	$7,181,400,421	0	0.0%	$0	0.0%	60	0.7%	$37,536,480	0.5%
Borough of Mountain Lakes	1,642	$1,183,405,498	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Netcong Borough	1,100	$695,081,980	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Parsippany-Troy Hills	17,064	$11,747,551,200	0	0.0%	$0	0.0%	10	0.1%	$3,955,495	0.0%
Township of Pequannock	5,642	$3,911,039,941	0	0.0%	$0	0.0%	6	0.1%	$1,715,180	0.0%
Township of Randolph	8,600	$6,709,486,516	1	0.0%	$1,034,098	0.0%	58	0.7%	$33,162,659	0.5%
Borough of Riverdale	1,183	$1,165,082,666	3	0.3%	$1,321,762	0.1%	1	0.1%	$1,087,914	0.1%
Borough of Rockaway	2,617	$1,612,749,951	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Township of Rockaway	11,485	$7,225,058,745	9	0.1%	$3,891,595	0.1%	10	0.1%	$4,214,865	0.1%
Township of Roxbury	9,544	$5,918,169,131	2	0.0%	$1,494,182	0.0%	9	0.1%	$5,665,590	0.1%
Borough of Victory Gardens	339	$163,035,099	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%

Municipality	Total Number of Buildings	Total Replacement Cost Value (RCV)	Class A				Class B			
			Number of Buildings - Class A	% of Total	RCV - Class A	% of Total	Number of Buildings - Class B	% of Total	RCV - Class B	% of Total
Township of Washington	8,062	$5,265,032,309	7	0.1%	$4,539,320	0.1%	110	1.4%	$56,195,921	1.1%
Borough of Wharton	2,051	$1,539,335,501	0	0.0%	$0	0.0%	0	0.0%	$0	0.0%
Morris County (Total)	**189,129**	**$127,068,881,137**	**160**	**0.1%**	**$74,895,407**	**0.1%**	**673**	**0.4%**	**$421,361,291**	**0.3%**

Sources: Morris County 2019; Microsoft, 2018, Open Street Map, 2019; NJOIT, 2018; NJGWS, 2015

Note: NJGWS New Jersey Geological Water Survey
RCV Replacement Cost Value
Class A includes classes AI, AII, AIV, AVI which is strongly cemented rock at varying slope angles. Class B includes classes BIII, BIV, and BV which includes weakly cemented rock and soil at varying slope angles.

Table 4.3.7-3. Number of Buildings on Carbonate Rock by Municipality

Municipality	Total Number of Buildings	Total Replacement Cost Value (RCV)	Carbonate Rock			
			Number of Buildings - Carbonate	% of Total	RCV - Carbonate	% of Total
Town of Boonton	3,262	$1,832,625,537	0	0.0%	$0	0.0%
Township of Boonton	1,898	$1,388,780,135	0	0.0%	$0	0.0%
Borough of Butler	2,701	$1,489,686,071	0	0.0%	$0	0.0%
Chatham Borough	3,286	$1,673,960,469	0	0.0%	$0	0.0%
Chatham Township	4,080	$2,300,237,613	0	0.0%	$0	0.0%
Chester Borough	853	$694,668,411	0	0.0%	$0	0.0%
Chester Township	3,680	$2,782,631,274	266	7.2%	$238,625,868	8.6%
Denville Township	7,198	$4,397,845,504	0	0.0%	$0	0.0%
Town of Dover	4,514	$2,640,787,978	0	0.0%	$0	0.0%
Township of East Hanover	4,848	$4,740,072,304	0	0.0%	$0	0.0%
Borough of Florham Park	3,805	$3,768,421,982	0	0.0%	$0	0.0%
Township of Hanover	7,090	$5,609,469,027	0	0.0%	$0	0.0%
Township of Harding	2,230	$1,808,255,972	0	0.0%	$0	0.0%
Township of Jefferson	9,625	$4,421,074,958	410	4.3%	$173,839,550	3.9%
Borough of Kinnelon	4,093	$2,858,766,250	0	0.0%	$0	0.0%
Borough of Lincoln Park	4,166	$2,125,371,898	0	0.0%	$0	0.0%

Municipality	Total Number of Buildings	Total Replacement Cost Value (RCV)	Carbonate Rock			
			Number of Buildings - Carbonate	% of Total	RCV - Carbonate	% of Total
Township of Long Hill	3,643	$2,253,461,094	0	0.0%	$0	0.0%
Borough of Madison	6,301	$3,066,320,935	0	0.0%	$0	0.0%
Borough of Mendham	2,139	$1,479,178,043	7	0.3%	$1,846,877	0.1%
Township of Mendham	2,667	$2,099,041,883	163	6.1%	$146,701,758	7.0%
Township of Mine Hill	1,590	$766,971,485	228	14.3%	$67,867,046	8.8%
Township of Montville	8,179	$6,714,034,036	0	0.0%	$0	0.0%
Township of Morris	9,713	$6,091,077,654	0	0.0%	$0	0.0%
Borough of Morris Plains	2,378	$1,738,775,034	0	0.0%	$0	0.0%
Town of Morristown	4,413	$2,945,511,672	0	0.0%	$0	0.0%
Borough of Mount Arlington	2,333	$1,065,424,961	0	0.0%	$0	0.0%
Township of Mount Olive	9,115	$7,181,400,421	1,962	21.5%	$1,848,104,162	25.7%
Borough of Mountain Lakes	1,642	$1,183,405,498	0	0.0%	$0	0.0%
Netcong Borough	1,100	$695,081,980	0	0.0%	$0	0.0%
Township of Parsippany-Troy Hills	17,064	$11,747,551,200	0	0.0%	$0	0.0%
Township of Pequannock	5,642	$3,911,039,941	0	0.0%	$0	0.0%
Township of Randolph	8,600	$6,709,486,516	145	1.7%	$431,935,389	6.4%
Borough of Riverdale	1,183	$1,165,082,666	330	27.9%	$171,719,149	14.7%
Borough of Rockaway	2,617	$1,612,749,951	0	0.0%	$0	0.0%
Township of Rockaway	11,485	$7,225,058,745	231	2.0%	$577,508,792	8.0%
Township of Roxbury	9,544	$5,918,169,131	3,730	39.1%	$2,579,739,945	43.6%
Borough of Victory Gardens	339	$163,035,099	0	0.0%	$0	0.0%
Township of Washington	8,062	$5,265,032,309	1,910	23.7%	$1,550,901,735	29.5%
Borough of Wharton	2,051	$1,539,335,501	0	0.0%	$0	0.0%
Morris County (Total)	**189,129**	**$127,068,881,137**	**9,382**	**5.0%**	**$7,788,790,272**	**6.1%**

Sources: Morris County 2019; Microsoft, 2018, Open Street Map, 2019; NJOIT, 2018; NJGWS, 1999

Note: NJGWS New Jersey Geological Water Survey
RCV Replacement Cost Value

Impact on Critical Facilities

The spatial analysis shows that there are three critical facilities located in the identified landslide susceptibility hazard areas in the County. Two of these critical facilities are dams and one is a wastewater facility. In addition to critical facilities, a significant amount of infrastructure can be exposed to mass movements of geological material:

- *Roads*—Access to major roads is crucial to life-safety after a disaster event and to response and recovery operations. Landslides can block egress and ingress on roads, causing isolation for neighborhoods, traffic problems, and delays for public and private transportation. This can result in economic losses for businesses.
- *Bridges*—Landslides can significantly impact road bridges. Mass movements can knock out bridge abutments or significantly weaken the soil supporting them, making them hazardous for use.
- *Power Lines*—Power lines are generally elevated above steep slopes; but the towers supporting them can be subject to landslides. A landslide could trigger failure of the soil underneath a tower, causing it to collapse and ripping down the lines. Power and communication failures due to landslides can create problems for vulnerable populations and businesses.
- *Rail Lines* **–** Similar to roads, rail lines are important for response and recovery operations after a disaster. Landslides can block travel along the rail lines, which would become especially troublesome, because it would not be as easy to detour a rail line as it is on a local road or highway. Many residents rely on public transport to get to work around the county and into Philadelphia and New York City, and a landslide event could prevent travel to and from work.

An exposure analysis was completed to assess the number of miles that major highways intersect the geologic hazard areas. The analysis found that 3.2 miles of highway, 3.4 miles of highway, and 13.2 miles of highway are constructed on landslide susceptible soils Classes A and Class B, and carbonate rock (natural subsidence/sinkhole), respectively. This includes the following major roadways: I-80, US 46, US 206, NJ 10, NJ 23, NJ 15, I-287, and US 202.

Impact on the Economy

Geologic hazards can impose direct and indirect impacts on society. Direct costs include the actual damage sustained by buildings, property and infrastructure. Indirect costs, such as clean-up costs, business interruption, loss of tax revenues, reduced property values, and loss of productivity are difficult to measure. Additionally, ground failure threatens transportation corridors, fuel and energy conduits, and communication lines (USGS 2005). Estimated potential damages to general building stock can be quantified as discussed above.

Impact on the Environment

A landslide or sinkhole/subsidence event will alter the landscape. In addition to changes in topography, vegetation and wildlife habitats may be damaged or destroyed, and soil and sediment runoff will accumulate downslope potentially blocking waterways and roadways and impacting quality of streams and other water bodies. Additional environmental impacts include loss of forest productivity.

Furthermore, soil and sediment runoff can accumulate downslope potentially blocking waterways and roadways and impacting quality of streams and other water bodies. Mudflows that erode into downstream waterways can threaten the life of freshwater and/or coastal species (USGS 2001). The impacts of eroded landscape can travel for miles downstream into adjacent waterways and create issues for surrounding watersheds.

Figure 4.3.7-1 shows landslide susceptibility in Morris County. A majority of the County is not susceptible to landslides, however there are small areas throughout the County that are susceptible to landslide events (Class

AI, AII, AIV, AVI, BIII, BIV, and BV). An exposure analysis found that 46.6 square miles of Morris County is susceptible to the geologic hazard (4.7 square miles located in the Class A landslide susceptibility area; 6.9 square miles located in the Class B landslide susceptibility area, and 35.0 square miles located over carbonate rock and potentially susceptible to natural subsidence/sinkholes).

Future Changes that May Impact Vulnerability

Understanding future changes that effect vulnerability in the County can assist in planning for future development and ensure establishment of appropriate mitigation, planning, and preparedness measures. The County considered the following factors to examine potential conditions that may affect hazard vulnerability:

- Potential or projected development
- Projected changes in population
- Other identified conditions as relevant and appropriate, including the impacts of climate change

Projected Development

Any areas of growth could be potentially impacted by the geologic hazard if located within the identified hazard areas or downslope. In general, development of slopes is not recommended due to the increased risk of erosion, stormwater runoff and flooding potential. The additional runoff results in sedimentation of down slope surface waters, which damages habitat and has the potential to damage property. The sloping land increases the rate of runoff, which reduces the rate of groundwater infiltration.

Each municipality identified areas of recent development and proposed development in their community. Developments that could be located using an address or Parcel ID were geocoded and overlain with the landslide hazard areas to determine vulnerability to flooding. Four proposed new development locations may be susceptible to the landslide. Refer to Section 3 (County Profile), and Volume II Section 9 (Jurisdictional Annexes) for potential new development and geologic hazard areas in Morris County and Figure 4.3.7-6 which illustrates the proposed new development and the geologic hazard areas.

Projected Changes in Population

Morris County has been experiencing and is projected to continue experiencing a growth in population. As discussed above, several major roadways through the County are exposed to the geologic hazard, and an increasing population in the County and surrounding areas that utilize these roadways will result in a greater number of people exposed on a daily basis. Refer to Section 3 (County Profile) which includes a discussion on population trends for the County.

Climate Change

Climate change may increase the likelihood of landslides. Warming temperatures resulting in wildfires would reduce vegetative cover along steep slopes and destabilize the soils due to destruction of the root system; increased intensity of rainfall events would increase saturation of soils on steep slopes. Under these future conditions, the County's assets located on or at the base of these steep slopes will have an increased risk to landslides. Roadways and other transportation infrastructure located in these areas will also be at an increased risk of closure, which would impact the County's risk as described above .

Higher temperatures and the possibility of more intense, less frequent summer rainfall may lead to changes in water resource availability. The projection in the increase of average temperatures may lead to an increase in the frequency of droughts. Sinkhole activity intensifies in some karst areas increases during periods of drought. With an increase in drought periods, the number of sinkholes can increase (Linares et al. 2016). Additionally, changes to the water balance of an area including over-withdrawal of groundwater, diverting surface water from a large area and concentrating it in a single point, artificially creating ponds of surface water, and drilling new water wells will cause sinkholes. These actions can also serve to accelerate the natural processes of bedrock degradation, which can have a direct impact on sinkhole creation.

Change of Vulnerability Since 2015 HMP

The entire County continues to be vulnerable to the geological hazard. Several differences exist between the 2015 HMP and this update including updated hazard data and asset inventory data. As discussed in Section 4.2 (Methodology and Tools), an updated general building stock based upon replacement cost value from MODIV tax assessment data and 2019 RS Means, and an updated critical facility inventory were used to assess the County's risk to the identified hazards of concern. In addition, the 2017 American Community Survey population estimates were used and estimated at a structural level in place of the 2010 U.S. Census blocks. Updated hazard areas were used as well; since the 2015 HMP, the NJGWS has released updated landslide susceptibility data. This updated data was used to conduct the geologic hazard exposure analysis and to update HAZUS-MH's default earthquake data to evaluate the seismic hazard. Overall, the hazard area delineations remained unchanged, so any signification increase in vulnerability would be attributed to population growth and new development.

Figure 4.3.7-6. Potential New Development and Landslide Hazard Areas